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RESEARCH

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Compressed stabilized earth block: environmentally sustainable alternative for villages housing

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Abstract

Construction materials contribute to environmental pollution and the impoverishment of natural raw materials. The villages of Upper Egypt were exposed to high thermal loads owing to their geographical location. Moreover, the current building materials do not comply with the principles of sustainability and environmental adaptation of the residents of these buildings. Therefore, attaining admission to one sustainable building material in Upper Egypt and using it as an environmentally compatible, inexpensive, accessible, and easy building material for the users of these blocks is essential. In this study, the author selected various sites in Upper Egypt, analyzed climate and urban data, and after that, suggested prototypes with many variables and measured using the DesignBuilder V5 computer simulation program to select an optimal building type. Reached that can be saved energy about 40:50% and decreased annual discomfort hours more than 50%, finally, discussed with community members by a questionnaire on societal acceptance. The research concluded that building with compressed stabilized earth block is an environmentally sustainable solution applied in residential areas in the villages of Upper Egypt to reduce deficiencies in environmental adaptation.

Keywords: Compressed stabilized earth block, Environmental, Sustainable, Housing, Villages, Upper Egypt

Introduction

Environmental problems are central in the consciousness of researchers. Buildings and their materials are an essential part of the architectural product and have received much attention for preparing sustainable natural materials.

Soil has been a major component of buildings since antiquity, used in 6000 BC as a building material in Mesopotamian civilizations, the Tibetan and Andean in Peru, in the fertile valleys in China and Thebes in Egypt. Therefore, thousands of years ago, people lived sustainably, in accord with nature, and respected and benefited from it. However, construction using reinforced concrete and burned bricks has extended to negative impacts on the environment.

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Therefore, it is critical to produce environmentally friendly building materials and improve the characteristics of building materials, manufacturing, lower energy consumption, and simultaneously cut costs. Therefore, this study highlights the compressed stabilized earth block used in Upper Egypt villages as a solution to the problem of constructing housing units in these degraded areas [1–5].

The applied study was used to define areas as a case study. Thus, the research identified the analytical field area data and properties of the suggested material and deduced a set of variables measured according to their classification using a computer simulation program to find an optimal architectural model. Community members completed a questionnaire to examine the research hypothesis of the feasibility of construction using compressed stabilized earth block (CSEB) in the villages of Upper Egypt. Finally, the results are discussed, and recommendations are proposed.

Research aim and methodology

The research aim

investigates a sustainable building material for the construction of residential areas in Upper Egypt. Therefore how to use them as environmentally compatible, inexpensive, available, and easy to use materials. Furthermore, the study investigates the impact of these materials on the environmental adaptation of users of these areas.

Methodology

A research methodology was implemented to achieve the research objectives. First, qualitative research and analysis of the data were collected about construction using compressed stabilized earth block. Moreover, climate, urban, and building status of Upper Egypt villages. Then, qualitative and quantitative approach to suggested prototypes, its variables, and questionnaire. Analysis was used to identify the system through the data from the literature review, as well as knowing the degree of acceptance and satisfaction with this technology. The research limitations are Upper Egypt villages and CSEB as construction building materials.

Consequently, CSEB was identified as a low-cost and environmentally friendly material found in developing countries with hot climates or in tropical [6, 7].

It consists of a mixture (soil + fixing material, often 5% + water); stripped topsoil and only deep soils are used (Fig. 1) [8, 9].

The various components and stabilizers, such as Portland cement or lime, are mixed with clay soil and sand, with different percentages of mixing. The mold is compressed in the process (manual or automatic compression) and dried for 28 days; however, it does not burn [10–12] (CSEB = soil + water + stabilization (fixing material) (Table 1).

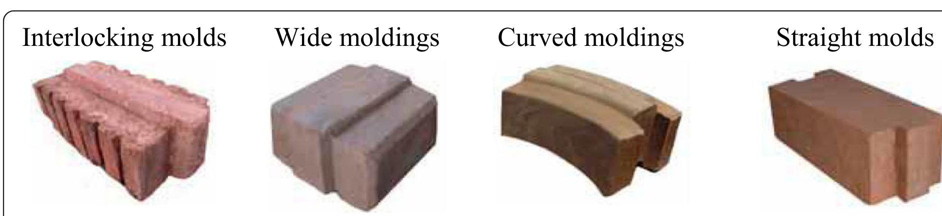


Fig. 1 Examples of compressed stabilized earth block

Table 1 Fixings used to improve soil properties in (CSEB) [13–16]

Stabilization	Soil Components			
	Gravel	**Sand**	**Silt**	**Clay**
Cement (it is more sandy than clayey)	15%	50%	15%	20%
Lime (it is more clayey than sandy)	15%	30%	20%	35%

Natural building materials, such as soil in general and specially CSEB are an ideal solution in hot areas because of the thermal comfort and insulation of the soil and its low impact on the environment. Table 2 lists the advantages and disadvantages of the CSEB technique [17–20].

Also by CSEB in constructions, it decreases carbon dioxide emission 2 to 7 times less than that of burned bricks (Fig. 2).

Several buildings with different activities and designs in many hot-climate countries (not limited to developing countries) and clarifies the advantages of using the CSEB, Table 3 shows some examples.

Table 2 The advantages and disadvantages of using CSEB in construction [21–31]

CSEB properties	Composition and construction	Economic impact	Energy efficiency	Social acceptance
- Uniform blocks size and dimensions	•	•		•
- Density (high)	•	•	•	
- Durability to external weather conditions.	•	•	•	•
- Maintenance. (little)	•	•		•
- Water resistance (not waterproof)	•	•	•	
- Social and economic stability of users		•		•
- Diversity in the final product (according to user's requirement and economic condition)		•		•
- Colors of final block is according to the soil used (good)		•		•
- Not needing for finishing.		•		•
- Raw materials used are from the natural soil.	•	•		•
- Less quantities of bonding material (mortar).	•	•		•
- Manufacturing takes place on site (transportation costs).	•	•		•
- Little time from construction (reducing costs)		•	•	•
- Techniques, in manufacturing or construction.	•	•		•
- Local workforce (reduce overall costs).		•		•
- Job opportunities.		•		•
- The equipment is uncomplicated and low-cost		•		•
- Easy to use suitable equipment		•		•
- Energy is consumed (less) (consumes 5 to 15 times less energy per m^3 than that used in burned bricks [7])		•	•	•
Pollution emission (less)			•	•
Indoor comfort condition (improve)		•	•	•
Carbonless.		•	•	•
Thermal insulation (good)		•	•	•

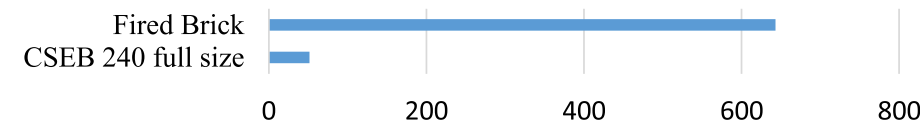


Fig. 2 CO_2 emission ($KgCO_2/m^3$) comparison (fired brick/ CSEB) [32, 33]

Recently, the Egyptian Center for Housing and Building Research interested in CSEB as the best method for sustainable construction, especially in developing areas of state development efforts. The rise of prices for building materials has resulted in higher housing prices in Egypt, such as iron and cement. Therefore, Egypt adopted the Egyptian building code of CSEB [38].

Methods/experimental

Six villages were chosen from different governorates in Upper Egypt (Giza, Fayoum, Dahkla, Assuit, Aswan, and the Red Sea) as a case study, shown in Fig. 3.

Reasons to choose villages in Upper Egypt as a case study are as follows:

1- These villages are deprived, with challenges for economic growth are characterized by low construction standards and comfort for users and a lack of services and infrastructure.
2- With the increasing population of these villages, the need to provide low-cost construction materials for housing is an alternative to using traditional building materials.
3- Burned clay blocks remain the main construction material, even though it is a huge source of greenhouse gasses (GHGs) [39, 40].
4- In general, Upper Egypt is in the southern part of Egypt. The warm, arid climate provides a comfort zone for construction and urbanization. Overall, a lack of sustainability exists in the villages in Upper Egypt (socially, economically, and ecologically). Therefore, the Upper Egyptian villages were chosen as a case study [41]. Table 4 conclude its main data.

Climatic data for case studies was higher temperatures in summer reach 35–45 °C, whereas lower temperatures in winter can reach 15–20 °C, and rain is scarce [42] (Fig. 4).

The figure shows that most of the temperatures are outside the thermal comfort zone (shaded part).

The main building material in these villages is burned brick in most buildings in the village and wood and stones (Fig. 5).

The aim is to build and retrofit buildings in Upper Egypt using local and stronger materials to obtain a better thermal and esthetic shelter.

Method: After the analytical study, a set of variables was observed and evaluated using the alternative proposal design to arrive and an ideal suggested model.

Design variables: The variables chosen were reduced energy loads, thermal comfort, energy consumption, budget, lifecycle, and social acceptance. Table 5 shows the design parameters.

Table 3 Shows Different types of CSEB International buildings

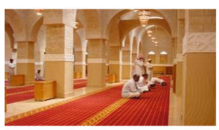
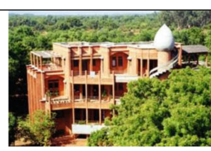
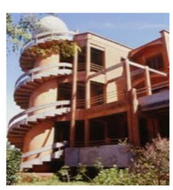
  Tanouan IBI	Primary School Tanouan IBI, Mali 2012. CSEB was the traditions and culture of the region. Arched roof structures used to give the largest possible space without the hurdles of interior building. With an area of 7 x 9 m^2 = 180 students, with a total area of 200 m^2 for the school. Built by community members, using CSEB to build resilience in the environment, consistent with the way it converges on all Mali's villages. Design Provide natural lighting and ventilation in the roof openings and closed in the rainy season [34].
  Al Medy mosque	Al Medy mosque Saudi Arabia 2004. Medi Mosque, winner of the Aga Khan Award for Architecture in 2007. In 2010 the project won the first prize, "Prince Sultan Bin Salman Award for Architectural Heritage" The area of the mosque is 420 m2, covered with a domed ceiling and a minaret, with a height of 18.05 meters. Built-in just 7 weeks with semi-skilled labor [35].
  Vikas Community	Vikas Community, 1998. The Community includes 23 housing units with a capacity of 50 persons, a total area of 1448 m^2, the Vikas community won the World Habitat Award 2000 all buildings by CSEB and adding 5% of Cement as a stabilizer, the roof of the building is domes and vaults, and its height is 13.40 m. Smart Energy Building used an application of renewable energy technologies, Natural ventilation and sun protection, Integration into the land, depending on nature, existing trees, etc. [36].
  Women's Health Centre	Women's Health Centre, Burkina Faso, 2007. The Women's Health Center in Burkina Faso, on an area of 500 square meters, established by CSEB. This project won the Health Category Award at the International Architecture Festival. Built on-site using CSEB. Due to the energy shortage in the region, the center integrated into controlling the consumption and self-production of renewable resources .Good steering, reducing the impact of hot winds, and use in mutual shading against direct sunlight exposure [37].

Fig. 3 Case study areas map

Each variable was measured using either computer simulation or a questionnaire, depending on the variable type.

Simulations

The simulation program is DesignBuilder V5 and design proposal type as shown in Table 6.

Questionnaires

A sample is taken from the chosen community, and 20 questionnaires were distributed in each village.

Factors and variables, to research the drivers and barriers of CSEB building technology in Upper Egypt, with analytical, and not statistical, generalization. Questionnaire forms were filled out from the sample of the study population with semi-structured interviews. The issues under question were shown in Table 7.

Result

Simulation

The simulation program is DesignBuilder. All 84-simulation readings in six countries and two classes of readings were obtained from the annual energy consumption and annual thermal comfort indicators. The analysis is as shown in Table 8.

From Table 8, we conclude a better-proposed building model in each governorate, which achieved the least number of hours of thermal discomfort and less energy consumption. Figures 6 and 7 show the energy consumption in the model and the amount of energy saving.

Table 4 Data of case study areas

Located in Upper Egypt	North	North	Middle	Middle	South	South
Population density	High	medium	low	High	medium	low
Construction situation needs	Retrofit	Retrofit	New building	Retrofit	Retrofit	New building
Climate zones	Semi desert	Hot desert	Hot, dry desert	Dry desert	Very dry desert	Hot coastal
Soil type	Clay	Mixed	Sand	Clay	Mixed	Sand
	Giza	**Fayoum**	**Dahkla**	**Assuit**	**Aswan**	**Red Sea**

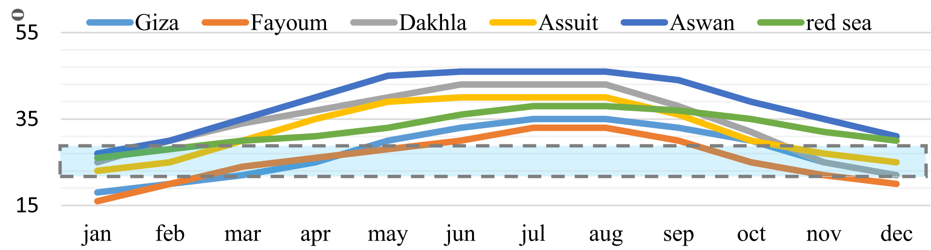


Fig. 4 Monthly most temperatures (°C) in choosing areas. Source: World meteorological organization

Questionnaire

A sample was taken from the study community and 20 questionnaires were distributed in each village (quantitative method) to obtain the residents' ability to use CSEB construction as an alternative to the traditional building materials used in the region. Fig. 8.

Discussion

CSEB is an environmentally friendly substance with high thermal insulation properties and strength and durability, contributing to the thermal comfort of its users and enhancing the health of the population (indoor houses are cooler in summer and warmer in winter).

The model with code $B_1T_2R_2F_2C_1$ includes CSEB with 5% cement, 24 cm wall thickness, a curved roof type, ground and one floor with a vertical courtyard position is achieves the best results in most governorates, which can be generalized in Upper Egypt and its results analyzed below in Table 9.

The residents' opinions were obtained regarding the proposed model and the results correlated with most of the sample (Fig. 9).

CSEB will have great potential in the future to build low to medium-cost housing and contribute to sustainable development and was accepted by the residents of the villages, as indicated in the results of the questionnaire.

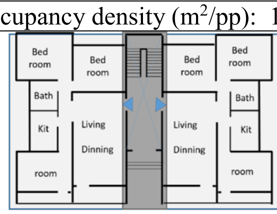
Fig. 5 Buildings state in the case study areas, by researcher, 3-10-2019

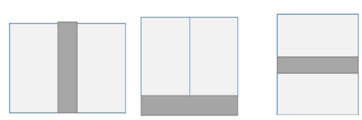
Table 5 Design parameters

Climate (case study regions	(Giza. A_1) - (Fayoum. A_2) - (Dakhla.A_3) - (Assuit.A_4) - (Aswan.A_5) - (Red sea. A_6).	
	Simulation case	Base case
- Construction material	CSEB (with5% cement. B_1) – (with 5% lime. B_2)	Fired brick
- Wall thickness	CSEB (32cm. T_1) -(24 cm. T_2) -(13 cm. T_3)	(25cm-12cm)
- Roof type	(Flat. R_1) – (curved. R_2) – (sloping. R_3)	Flat roof
- No. of floor	(Ground. F_1) - (ground and first. F_2) – (ground and 2 typical. F_3)	
Design and courtyard position.	(C_1- C_2- C_3) Types of building design. By: researcher.	

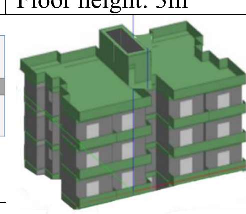
Table 6 Building specification

Building type: residence				Floor area: 100 m^2	
Occupancy density (m^2/pp): 15m^2/pp				Floor height: 3m	





Type C_1 C_2 C_3



Simulation model

Living &dinning 24m^2- 2:3 bed room 16m^2 each- 1 bathroom 4m^2- 1 kitchen 6m^2 – courtyard 48m^2 (approximately).

Building types and model. By: researcher.

Used building material (source researcher). [43]					
Building material	wall	roof	Coefficient of conductivity	Compression strength	Tensile strength
CSEB 5% Cement	32*24*13 24*24*13	14*7*7c m blocks	0.65 W/m*c	6Mpa	1.5Mpa
CSEB 5% lime	24*13*13 cm blocks	for domes and vaults	1.26 W/m*c	4Mpa	0.9 Mpa
				1Mpa=10kg/cm^2	

Opening &R Value: (according to the Egyptian energy efficiency code for building)		
	(WWR) Window wall ratio.	(R value) Resists the flow of heat.
North& South	20-30%	1.00
East &west	≤20%	1.30

Glazing type					
Window type	Blends	Window area	Still Height	Frame	(SHGC) fraction of solar radiation through a window
Single clear. 6mm.	Internal blends	1.50m* 4.00m	0.80	Painted wooden	Don't count

Table 7 Issues raised

Environmental	**Carbon abatement** **Innovation** **Environmental rating** **Sustainable** **Potential contamination** **energy efficiency** **indoor comfort conditions** **Lifespan and durability** **Building Adaptation** **Heat transfer** **Reliability** **Complexity** **Adaptable**
Economic	Value Of The End Product The cost of production Scalability Costs time for construction special technologies in manufacturing job opportunities Locally Flexibility
Social	Maintenance Health and safety Nontoxic Resistance Power of vested interests Incentivizing technology Retrofit issues

Using this technology in the villages of Upper Egypt will achieve many advantages and benefits (economic, social, and environmental) and enhance urban development in the villages of Upper Egypt.

Conclusions

Compressed Stabilized Earth Block is one of the world strategies and trends towards back to nature to saving the planet, and producing zero-energy buildings, preserving the environment and quality of life.

The study proved that replacing the traditional building material with CSEB while fixing the other proposed variables in the six governorates in Upper Egypt

Table 8 Max/Min discomfort hours and energy consumption in building types.

Max. /min discomfort hours				Max/min energy consumption	Kwh/m^2
	Hours	Building type (code)			
Giza	2365 1005	A_1	$B_2\ T_3\ R_1\ F_3\ C_2$ $B_1\ T_2\ R_3\ F_2\ C_1$		205 44.3
Fayoum	2340 950	A_2	$B_2\ T_3\ R_1\ F_3\ C_3$ $B_2\ T_2\ R_3\ F_2\ C_1$		184 32
Dakhla	2036 1170	A_3	$B_2\ T_1\ R_3\ F_2\ C_3$ $B_1\ T_1\ R_2\ F_1\ C_2$		255 54
Assuit	2055 1040	A_4	$B_1\ T_3\ R_1\ F_1\ C_2$ $B_1\ T_2\ R_2\ F_2\ C_1$		292 92.5
Aswan	2210 1280	A_5	$B_2\ T_3\ R_3\ F_3\ C_3$ $B_1\ T_1\ R_2\ F_1\ C_2$		355 94
Red Sea	2001 1340	A_6	$B_1\ T_3\ R_1\ F_3\ C_3$ $B_1\ T_2\ R_2\ F_2\ C_1$		310 84.6

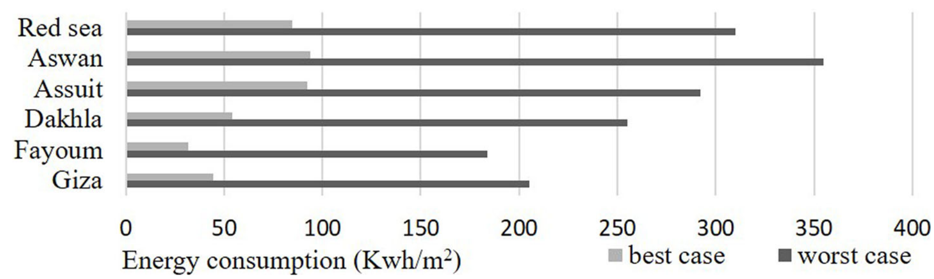


Fig. 6 Energy consumption in the best/ worst building types

under investigation reduced the thermal discomfort hours, raising the efficiency of the built environment and the Energy consumption decreased from 35 to 50%. Therefore, building with compressed stabilized earth block is an environmentally sustainable solution applied in residential areas in the villages of Upper Egypt to reduce deficiencies in environmental adaptation. Therefore, the research hypothesis is right.

The proposed design considerations, such as the wall thickness, the shape of the roof, and internal court position help to increase energy efficiency and reduce consumption. The best model with the code $B_1T_2R_2F_2C_1$ (Fig. 7) is effective for the thermal comfort of users.

From the questionnaire analysis for residents, there was a great tendency towards adopting these new ideas in construction, the environmental and thermal impact of CSEB would positively affect user satisfaction rate at ~ 65%, due to currently environmental pollution. Some also supported the idea because it is economically, rising in housing prices in Egypt because of higher prices for building materials, such as iron and cement, which reflected resident, so The cheapness of CSEB and the ease of use had the greatest impact on its social acceptance, at a rate of ~ 75%.

Some were worried about maintenance, the rate at ~ 30% of people were concerned about the durability and its final look and needing a multistory building (more than 5 floors).

Land locations like Egypt's sandy desert soil are suitable construction materials and achieve sustainability.

The research concludes that the CSEB house is a promising passive solution for saving energy. The hot desert climate in Egypt has resulted in a decrease in energy demand of between 35% and 50%.

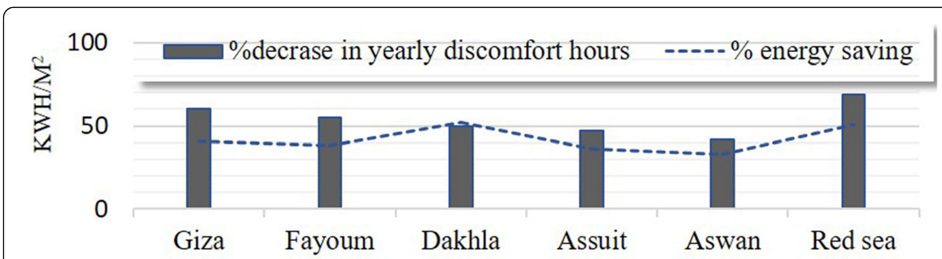


Fig. 7 Decrease in yearly discomfort hours and amount of saving in energy

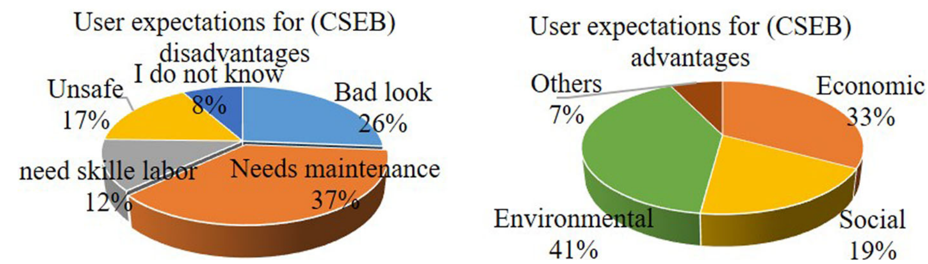


Fig. 8 User expectation for (CSEB) advantages / disadvantages

Table 9 Best-case analysis. By: researcher

Decrease in yearly discomfort hours	**62%**
Average Annual energy demand	42 Kwh/m^2
Energy saving	48%

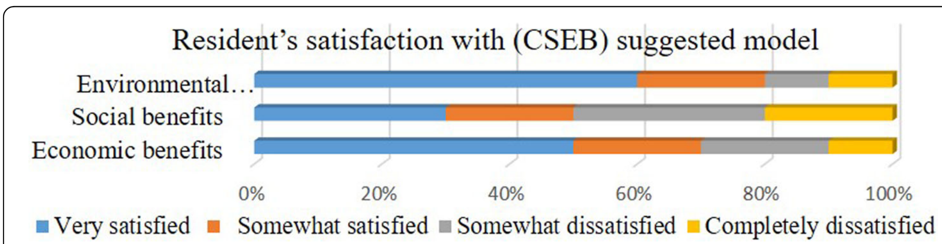


Fig. 9 Resulted of the screening questionnaire

prefer CSEB houses because it has potential in energy saving, reduced maintenance and operating costs, lower environmental impact, construction efficiencies facing expansions and contractions in arid climates, dual land use with minimal visual impact because landscaped areas replacing the building leave better visual images, and lower noise. Furthermore, it has low carbon emissions, does not disturb the ecosystem, and is an adaptable subject and suitable for culture, customs, and traditions.

Abbreviations
CSEB: Compressed stabilized earth block; WWR: Window wall ratio; *R* value: Resists the flow of heat from the window or a complete wall or ceiling; SHGC : The fraction of incident solar radiation admitted through a window

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Author's contributions
Not applicable

Authors' information
'W.H' is an author: Architecture, environmental Design in Ain Shams University (BSc. MSc., PhD.), a member in Advisory Committee – Egypt Society of Energy Efficiency Engineers and Investors.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The author declares that they have no competing interests

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